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compact gamma camera**

Yujin Qi

Chinese Academy Science, yujin@uow.edu.au

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Abstract

The aim of this study to design optimized pinhole and parallel-hole collimators for the development of a high-resolution microSPECT system using a compact pixelated scintillation detector. The detector has a field-of-view of 11 cm with pixelated crystal elements of 1.0 mm pixel size and 1.12 mm pixel pitch. The relative resolution and sensitivity advantages of pinhole and parallel-hole collimators for mice and rats imaging were investigated using analytic formulations and Monte Carlo simulations. The optimized collimator designs were obtained by maximizing the system detection efficiency for a given object resolution. The collimator designs were optimized for 140 keV incident gamma photons. Our results indicate that this small field-of-view compact detector fitted with a conventional high-resolution parallel-hole collimator with 4 cm hole-length and 1.2 mm hex hole-size could not provide better than 2 mm resolution for mice and rats imaging. However, a pinhole collimator with 10 cm focal length and 1.0 mm aperture size with keel-edge design of 0.5 mm channel-height can provide the desired resolutions for imaging mice and rats. The relative efficiency is about 2 times higher than that of the parallel-hole collimator for imaging mice at the distance of 3 cm from the collimator. In conclusion, pinhole collimator is superior to parallel-hole collimator and requires sophisticated optimal designs with high-resolution compact gamma camera for small animal imaging.

Keywords

camera, compact, imaging, spect, animal, small, gamma, designs, optimized, collimator

Disciplines

Engineering | Science and Technology Studies

Publication Details

Qi, Y. (2005). Optimized collimator designs for small animal SPECT imaging with a compact gamma camera. Proceedings of the 2005 IEEE Engineering in Medicine and Biology 27th Annual Conference (pp. 1780-1782). USA: IEEE.

Optimized Collimator Designs for Small Animal SPECT Imaging With a Compact Gamma Camera

Yujin Qi

Shanghai Institute of Applied Physics, Chinese Academy Science, Shanghai, China

Abstract— The aim of this study to design optimized pinhole and parallel-hole collimators for the development of a high-resolution microSPECT system using a compact pixelated scintillation detector. The detector has a field-of-view of 11cm with pixelated crystal elements of 1.0mm pixel size and 1.12mm pixel pitch. The relative resolution and sensitivity advantages of pinhole and parallel-hole collimators for mice and rats imaging were investigated using analytic formulations and Monte Carlo simulations. The optimized collimator designs were obtained by maximizing the system detection efficiency for a given object resolution. The collimator designs were optimized for 140 keV incident gamma photons. Our results indicate that this small field-of-view compact detector fitted with a conventional high-resolution parallel-hole collimator with 4cm hole-length and 1.2mm hex hole-size couldn't provide better than 2 mm resolution for mice and rats imaging. However, a pinhole collimator with 10cm focal length and 1.0mm aperture size with keel-edge design of 0.5mm channel-height can provide the desired resolutions for imaging mice and rats. The relative efficiency is about 2 times higher than that of the parallel-hole collimator for imaging mice at the distance of 3cm from the collimator. In conclusion, pinhole collimator is superior to parallel-hole collimator and requires sophisticated optimal designs with high-resolution compact gamma camera for small animal imaging.

I. INTRODUCTION

Recently more and more small field-of-view (SFOV) compact gamma cameras have been developed for high-resolution small animal imaging [1-4]. Those SFOV cameras are required dedicated collimator designs. Pinhole collimation and parallel-hole collimation have been employed for planar and SPECT imaging of small animals with compact pixelated gamma cameras. Pinhole collimation with imaging magnification has advantage for high-resolution, high sensitivity imaging of small object, while parallel-hole collimation has advantage where resolution requirements are not stringent and where larger objects must be imaged.

Parallel-hole collimations with conventional large field-of-view (FOV) scintillation cameras for human imaging have been extensively studied. However, the effects of pinhole and parallel-hole collimator parameters on system performance of small FOV gamma cameras have not yet been fully evaluated. So we seek a quantitative understanding of the relative resolution and sensitivity advantages of optimally designed pinhole and parallel-hole collimators for mice and rats imaging.

In this study the design of pinhole, parallel-hole and cone-beam collimators for small animal imaging is investigated as follows. A desired object resolution is specified for a pixelated detector with a given pixel size and intrinsic spatial

resolution, and for a given object-to-collimator distance. Then using analytic formula, the pinhole and parallel-hole collimator parameters are calculated that meet this object resolution with optimal geometric sensitivity. The goal of this analysis is to provide insight into collimator design and selection tradeoffs for small animal SPECT imaging studies.

II. METHODS

A. System Design Requirements

A compact microSPECT system for high-resolution small animal imaging is currently under development in the Shanghai Institute of Applied Physics, Chinese Academy of Science, China. The camera composed of a pixelated CsI(Na) crystal array and a 5" diameter Hamamatsu R3292 position sensitive PMT (PSPMT). The crystal array from Hilger Crystal Inc. was 110 mm square with 1.0x1.0 mm pixel elements, 1.12 mm pixel pitch and 3 mm crystal thickness. A novel charge division readout was used with this PSPMT. The effective field-of-view (FOV) of the camera was ~104 mm in diameter to provide a useful pixel array of 90x90.

This microSPECT system is designed primarily for imaging mice and rats with 140 keV gamma-ray. The required object resolutions in terms of full-width-at-half-maximum (FWHM) are ~1.5 mm for imaging mice at 3.0cm distance from the collimator, and 2.0 mm for imaging rats at 5cm distance from the collimator.

B. Optimum Collimator Designs

Parallel-hole and pinhole collimators were investigated for this compact camera. The parallel-hole collimator design was based on the theoretical calculations of the geometric response function of this compact gamma camera. The intrinsic resolution of the detector and the gamma-ray penetration effect on the resolution were taken into account in the calculations. A high-resolution parallel-hole collimator was investigated with required object resolution of 2.5mm at the object-to-collimator distance of 3.0cm. This leads to the optimal parameters of the parallel-hole collimator with flat-to-flat hex hole-size of 1.2mm, hole-length of 4.0cm and septa thickness of 0.2mm.

The pinhole collimator design was based on the formulations included in the literatures [5, 6], which provide theoretical predictions of the performance characteristics of a pinhole collimator. Using those formulas, the pinhole collimator parameters are calculated that meet the desired object resolution with optimal geometric detection efficiency. Then Monte Carlo simulation was performed to verify the optimized design.

In our design, the focal length and acceptance angle of the pinhole collimator need to be determined first. Their selections need to meet two criteria. One is that a normal-size mouse of ~3cm width should lie within the field-of-view of the imager. Another is that the sensitivity at the edge of the object should be no less than 2/3 of the sensitivity at a point on the central axis of the pinhole collimator. These requirements result in that the minimum acceptance angle of the pinhole collimator, $\alpha = 2 \cdot \arccos((2/3)^{1/3}) = 58.5^\circ$. Then based on the pinhole imaging geometry with the detector's size of 110mm, the focal length of the pinhole collimator was determined to be around 10 cm.

Then the pinhole aperture design was performed using high stopping power material of tungsten alloy. The relative resolution and detection efficiency of pinhole collimator with different aperture diameters from 0.6mm to 2.0mm were calculated. Then an optimal aperture diameter range was then determined according to the required object resolutions.

The pinhole aperture with keel-edge design was also investigated. Mont Carlo simulation was used to study gamma-ray penetration on the aperture edge. The keel-edge parameter

of channel height was varied from 0 mm (knife-edge) to 1 mm to examine the effects on the geometric sensitivity, penetration and scatter contributions, and imaging field-of-view of the pinhole collimator. Then the optimal channel height of the aperture would be determined from the tradeoff analysis.

III. RESULTS

A. System Spatial Resolution and Efficiency

Figure 1 shows the calculated system spatial resolutions and relative geometric efficiencies as a function of source-to-collimator distance for four pinhole apertures and a high-resolution parallel-hole collimator with a compact pixellated gamma detector. As compared to the high-resolution parallel-hole collimator, the pinhole collimator with smaller pinhole apertures (<1.5mm) can provide much improved spatial resolution. This high-resolution parallel-hole collimator cannot provide better than 2.0mm resolutions for imaging small animals. For imaging mice at a distance of 3 cm from the pinhole, less than 1.0mm pinhole aperture is needed in order to achieve 1.5 mm resolution, where the detection efficiency with 1.0mm pinhole is about 2 times higher than that of the parallel-hole collimator. For imaging rats at a distance of 5 cm from the pinhole, 1 mm pinhole aperture is also required to achieve 2.0 mm resolution.

B. Optimal Channel Height of Keel-edge Apertures

Table 1 summarizes the Monte Carlo simulated imaging characteristics of pinhole apertures with a knife-edge ($h=0$) and keel-edge design with four channel heights of 0.2mm, 0.5mm, 0.8mm and 1.0mm and the same 1.0mm aperture size. The results indicate that a keel-edge aperture with 0.5mm channel height provides ~18% improvement in spatial resolution compared to a knife-edge. Along the axis of the collimator, there is ~22% drop in the total efficiency but the drop in efficiency due to primary photons is only 3%. The drop-off as a function of distance from the collimator axis is faster for the keel-edge design.

TABLE I

Monte Carlo calculations of the performance characteristics of 1.0mm pinhole aperture with knife-edge ($h=0$) and keel-edge designs

h (mm)	Eff. (Tot)	Eff. (Pri.)	Geo. Fr.	Pen. Fr.	Scat. Fr.	FWHM (mm)	FWTM (mm)
0.0	1.00	1.00	0.71	0.279	0.011	1.141	1.828
0.2	0.92	0.98	0.86	0.134	0.006	1.015	1.493
0.5	0.78	0.97	0.94	0.056	0.004	0.942	1.386
0.8	0.67	0.96	0.96	0.048	0.002	0.922	1.342
1.0	0.59	0.95	0.97	0.029	0.001	0.920	1.336

In addition, the length of the channel height of the keel-edge aperture is also restricted by the aperture size and the acceptance angle. The length of keel edge should satisfy $h \leq d/\tan(\alpha/2)$, where h is the channel height, d is the aperture diameter and α is the acceptance angle. For a given cone angle of 30° , the maximum keel-edge lengths for different pinhole

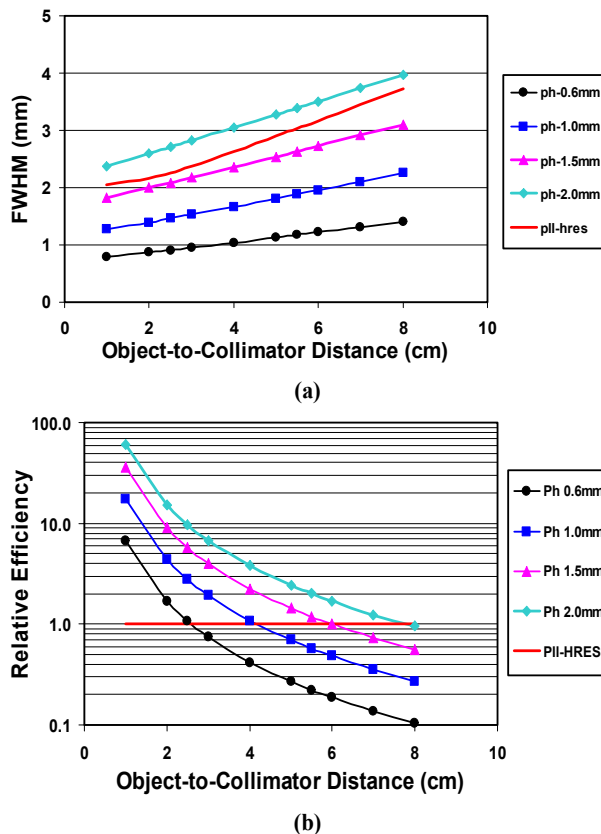


Figure 1. Theoretically calculated (a) spatial resolutions and relative geometric efficiencies (b) for optimized pinhole and parallel-hole collimators with compact pixellated detector plotted as a function of object-to-collimator/pinhole distance and pinhole diameter. The pinhole aperture diameters were varied from 0.6 mm to 2.0 mm. The focal length of the pinhole collimator is 10cm and the parallel-hole length is 4cm. The detection efficiency of pinhole collimator was normalized with respect to that of the parallel-hole collimator. Legend notation: ph=pinhole, pll=parallel-hole.

aperture diameters are listed in Table II. If the channel height of the keel-edge aperture was chosen larger than the maximum keel-edge height, the imaging FOV of the collimator would be got to reduce.

TABLE II

The effect of channel height on the collimator's field-of-view for a fixed acceptance angle of 60°

Aperture diameter (mm)	Max. channel height (mm)
0.6	1.04
1.0	1.73
1.5	2.60
2.0	3.46

Based on the above calculations and analyses, we have designed three pinhole apertures made of Tungsten alloy. The aperture diameters are 0.6, 1.0 and 1.5 mm and they had keel-edge with a channel height of 0.5 mm.

IV. DISCUSSION AND CONCLUSION

Although pinhole collimator provides a better tradeoff between spatial resolution and detection efficiency than the parallel-hole collimator, this advantage of the pinhole-collimator is obtained at the expense of a limit of imaging field-of-view. For imaging an entire small animal with good sensitivity near the edge of the field of view, parallel-hole collimator will be the best option.

The comparison of parallel-hole and pinhole collimators has been made using analytic formulas and is an initial effort towards understanding the relative resolution and sensitivity

advantages of parallel-hole and pinhole collimation for small animal imaging with compact pixellated detectors. This analysis method could be further extended to include the converging collimators with fan-beam and cone-beam for possible small animal imaging.

In our designs of the pinhole collimator, a 2/3 off-axis sensitivity threshold was used for selecting the focal length and acceptance angle of the pinhole collimator studied in this paper. Different criteria could be used that would result in different pinhole collimator parameters. The channel height of the keel-edge pinhole aperture is one of the key parameters in the pinhole aperture design. There exists a lower limit and an upper limit on the channel-height selection. The lower limit of the channel-height is determined to minimize the penetration and scatter effects while the upper limit is determined to obtain pinhole images with reasonable detection efficiency and to utilize entire field-of-view defined by the scintillation crystal array size.

In conclusion, pinhole collimator is superior to parallel-hole collimator and requires sophisticated optimal designs with high-resolution compact gamma camera for small animal imaging.

ACKNOWLEDGEMENT

The author would like to thank Dr. B.M.W. Tsui from the Division of Medical Imaging Physics, Department of Radiology, Johns Hopkins University for his guidance and criticism on the collimator designs.

REFERENCES

- [1] R. Wojcik, S. Majewski, D. Steinbach and A.G. Weisenberger, "High Spatial resolution Gamma Imaging Detector Based on 5" Diameter R3292 Hamamatsu PSPMT," *IEEE Trans. Nucl. Sci.*, vol. 45, no.3, pp.487-491, June, 1998.
- [2] D.P. McElroy, L.R. MacDonald, F.J. Beekman, Y. Wang, B.E. Patt, J.S. Iwanczyk, B.M.W. Tsui, and E.J. Hoffman, "Performance evaluation of A-SPECT: A high-resolution desktop pinhole SPECT system for imaging small animals," *IEEE Trans. Nucl. Sci.*, vol. 49, no. 5, pp. 2139-2147, 2002.
- [3] Y. Qi, B.M.W. Tsui, Y. Wang, B. Yoder, A. Weisenberger, R. Wojcik and S. Majewski, "Development and characterization of a high-resolution microSPECT system for small animal imaging", *Small-Animal SPECT Imaging*, Edited by M.A. Kupinski & H.H. Barrett, Springer Press, Chapter 23, July 2005.
- [4] N. Schramm, A. Wirrwar, F. Sonnenberg, and H. Halling, "Compact high resolution detector for small animal SPECT," *IEEE Trans. Nucl. Sci.*, vol. 47, pp. 1163-1167, June 2000.
- [5] H. O. Anger, "Radioisotope cameras," in *Instrumentation in Nuclear Medicine*, vol. 1, G. J. Hine, Ed. New York: Academic Press, 1967, pp. 485-552.
- [6] B.M.W. Tsui, "Collimator design, properties and characteristics," in *The Scintillation Camera*, G. H. Simmons, Ed. New York: The Society of Nuclear Medicine, 1988, pp. 17-45.
- [7] M.F. Smith and R. J. Jaszczak, "The effect of gamma ray penetration on angle-dependent sensitivity for pinhole collimation in nuclear medicine," *Med. Phys.*, vol. 24, no. 11, pp. 1701-1709, 1997.